Sandia National Laboratories provides DiMES Lithium samples

DiMES sample #106 with lithium metal insert – before exposure.

DiMES #106 is a graphite sample (ATJ) with a Li filled well (2.54 cm diameter, 1.3 mm deep).

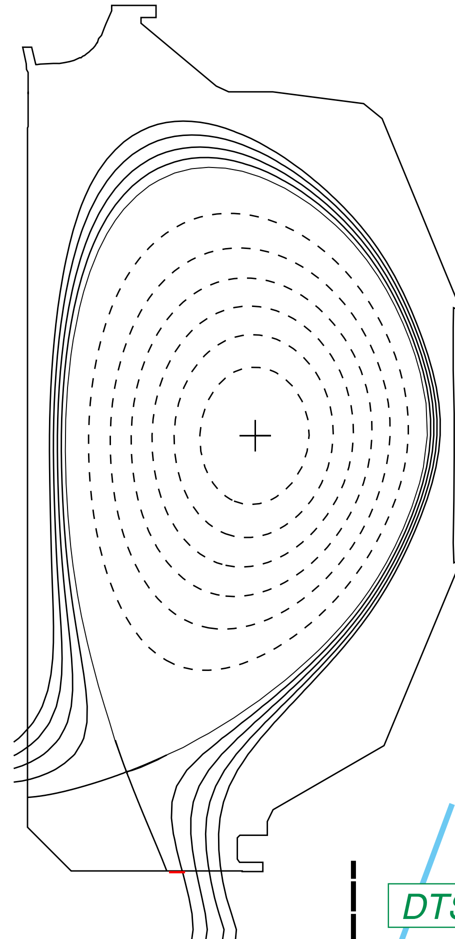
RB:SNL:8724:2000-0628-02

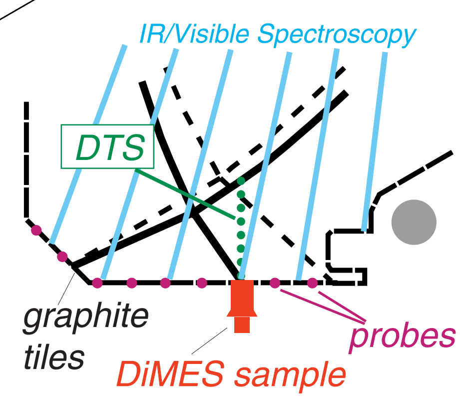
Sandia National Laboratories

A lithium sample was exposed to a very low power DIII-D divertor discharge

- Lower single-null plasma:
  - I_p = 1.1 MA, n_e = 2.5x10^{19} m^{-3}, B_T=2 T.
- L-mode confinement (i.e. no ELMs) maintained with very low heating power:

  P_{NBI} ~ 0.5 MW + P_{ohmic} ~ 0.7 MW = P_{in} ~ 1.2 MW.
- DiMES viewed by one spectrometer, three visible cameras and IR camera.
- Solid lithium sample: O.D. 2.54 cm, thickness 1.3 mm, all-graphite backing.

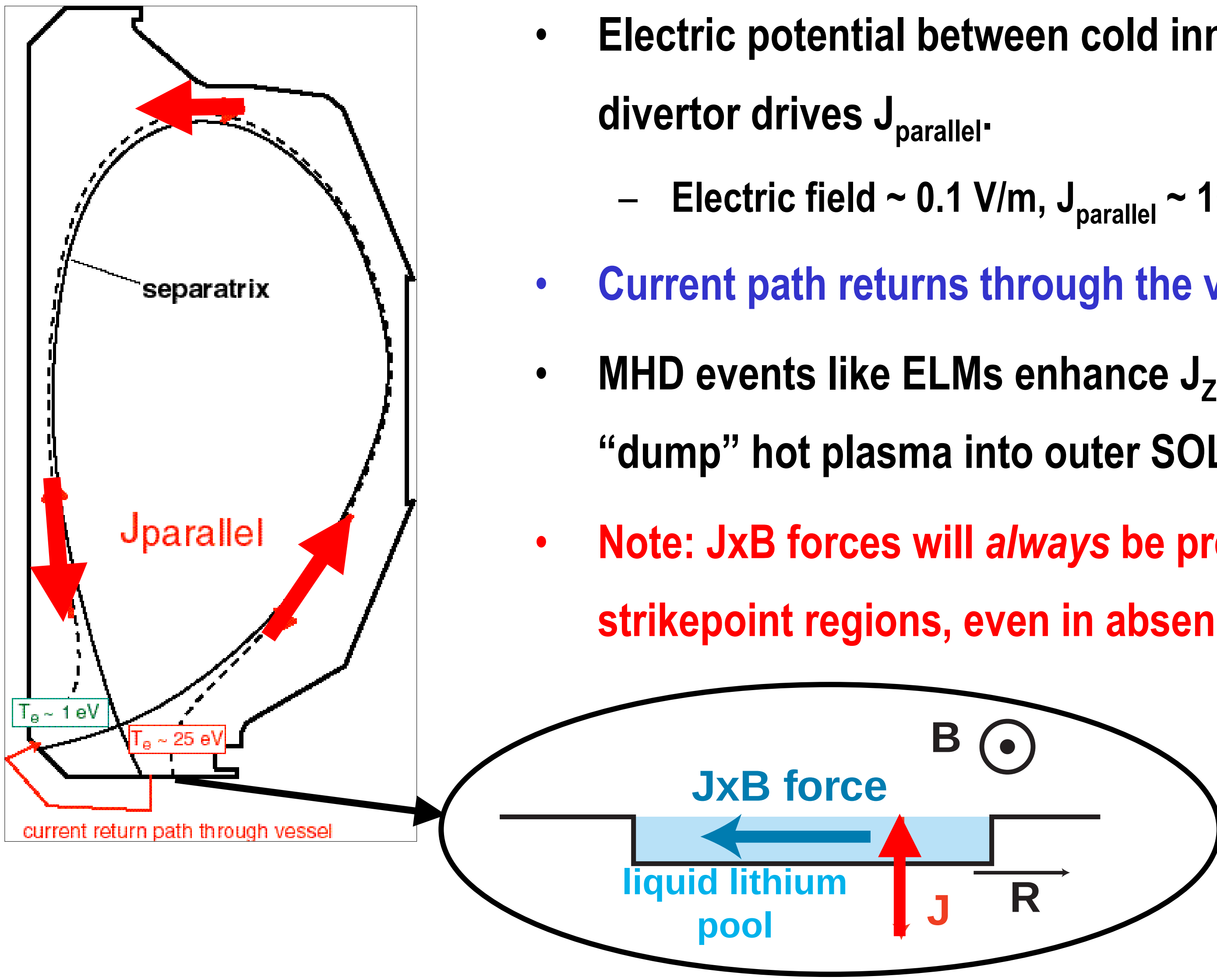




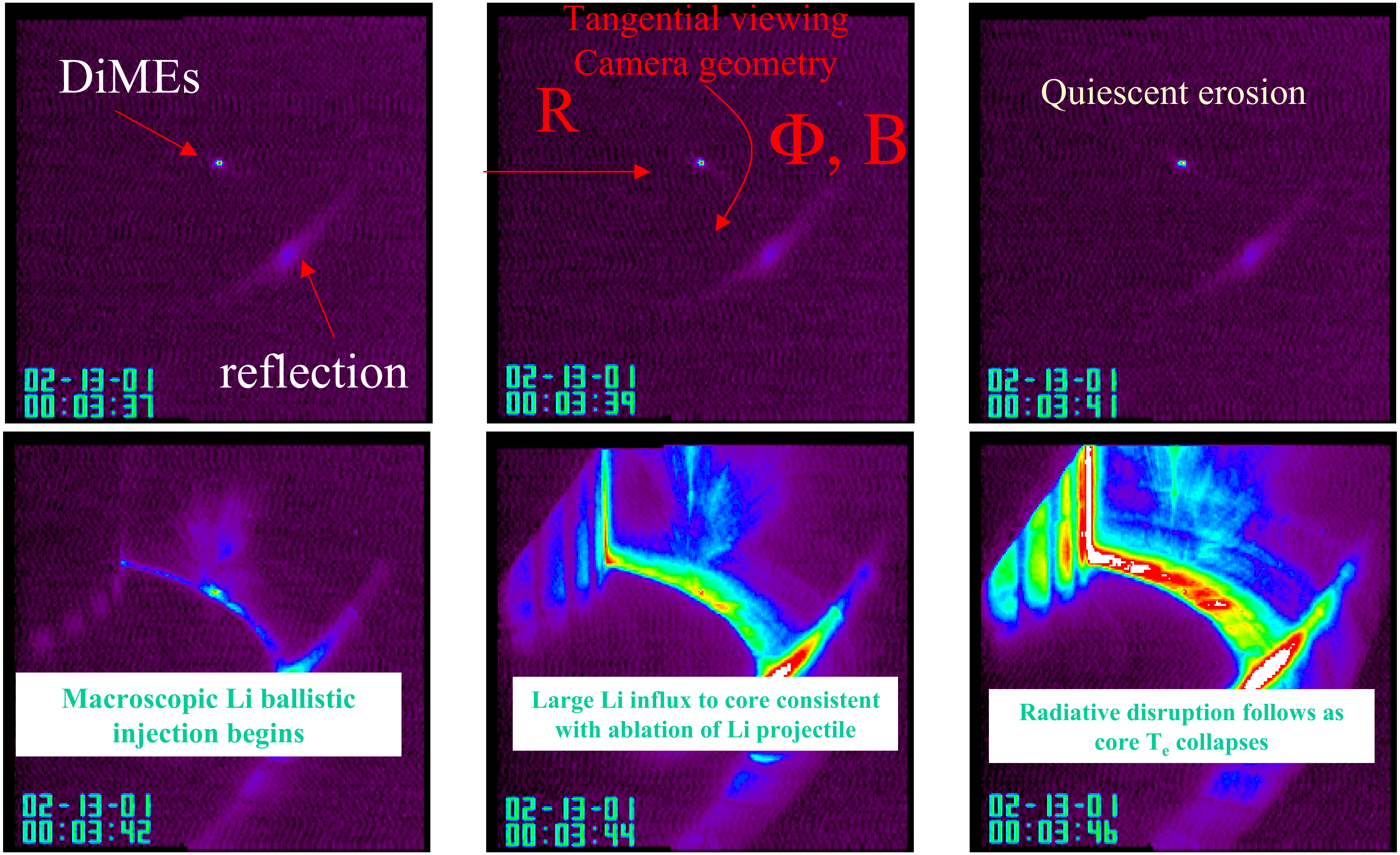
(This is nearly the lowest power discharge available in DIII-D)

Large currents are typically driven in the SOL of tokamak plasmas, giving rise to JxB forces at plasma-surface interfaces

- Electric potential between cold inner and hot outer divertor drives $J_{parallel}$.
  - Electric field ~ 0.1 V/m, $J_{parallel}$ ~ 10^5 A/m^2
- Current path returns through the vessel, J_Z
- MHD events like ELMs enhance J_Z because they "dump" hot plasma into outer SOL.
- **Note: JxB forces will *always* be present near strikepoint regions, even in absence of MHD events.**

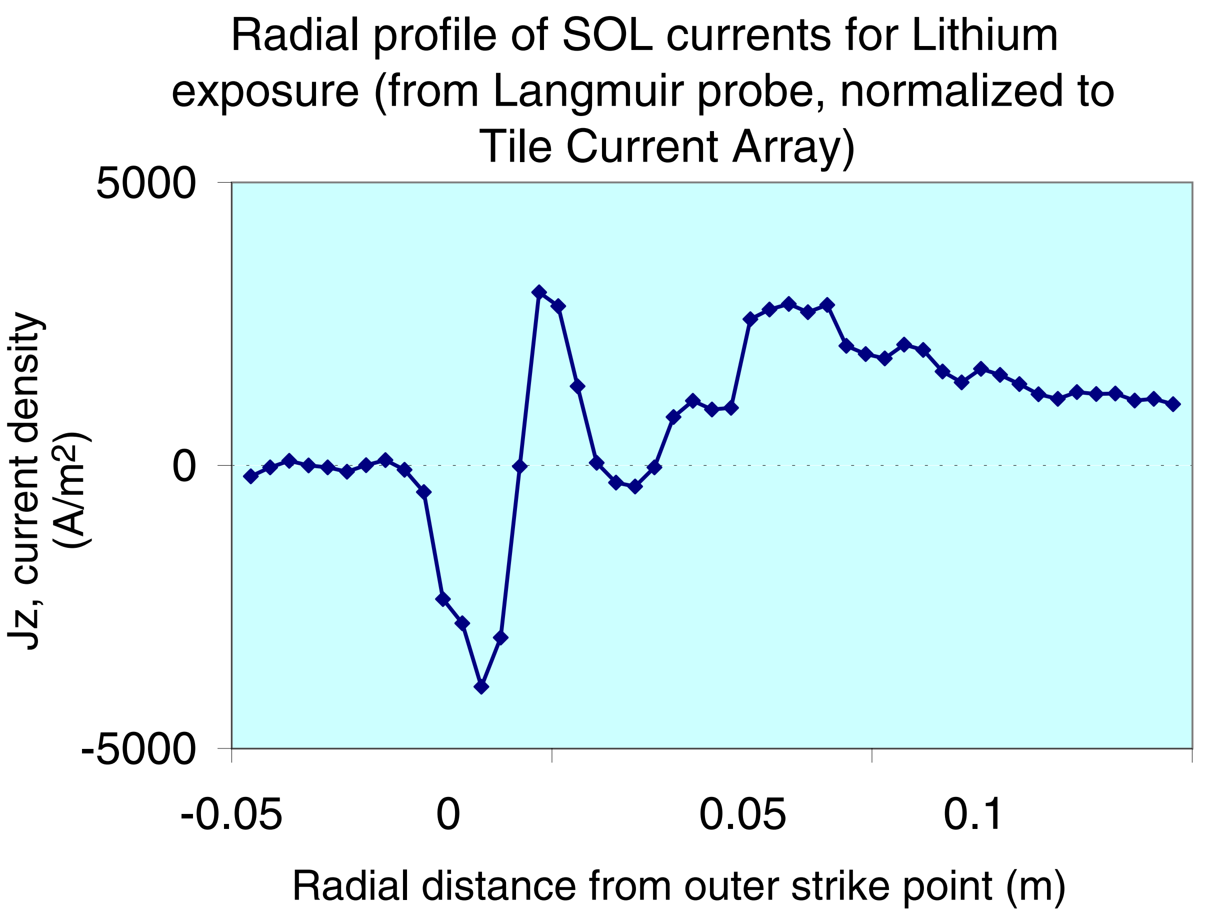


Video sequence of Li I light in divertor , following the large release of Li that causes the disruption (105511)

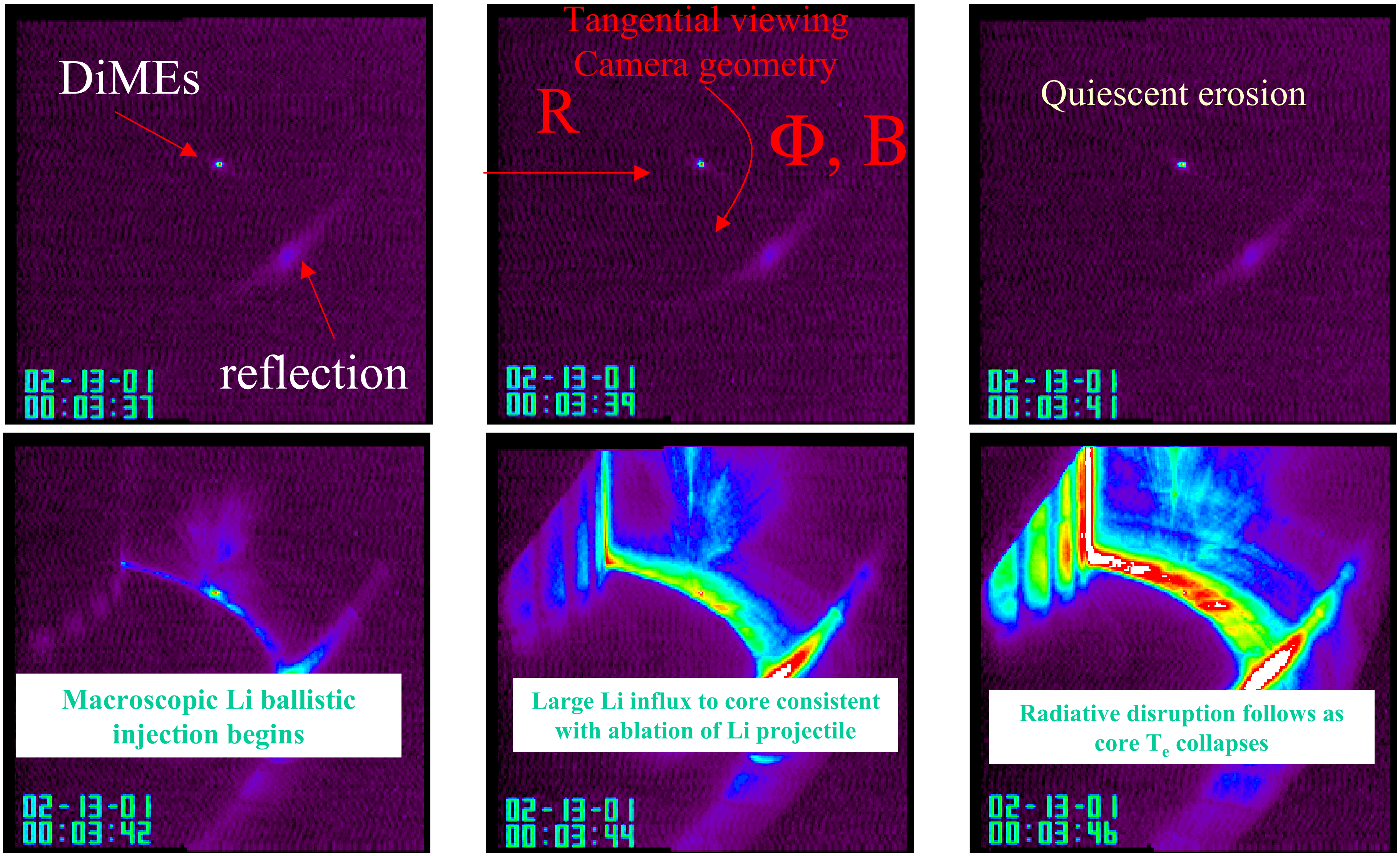


Measured SOL currents can have spatial variation across divertor plasma. Large gradients found near separatrix.

Low-power L-mode case



Video sequence of Li I light in divertor , following the large release of Li that causes the disruption (105511)



MHD Analysis of Lithium Sample in DiMES/DIII-D

Neil Morley (UCLA), Clement Wong (GA)

APEX/ALPS Meeting

Princeton Plasma Physics Laboratory

November 5, 2002

2D Free Surface Flow Model

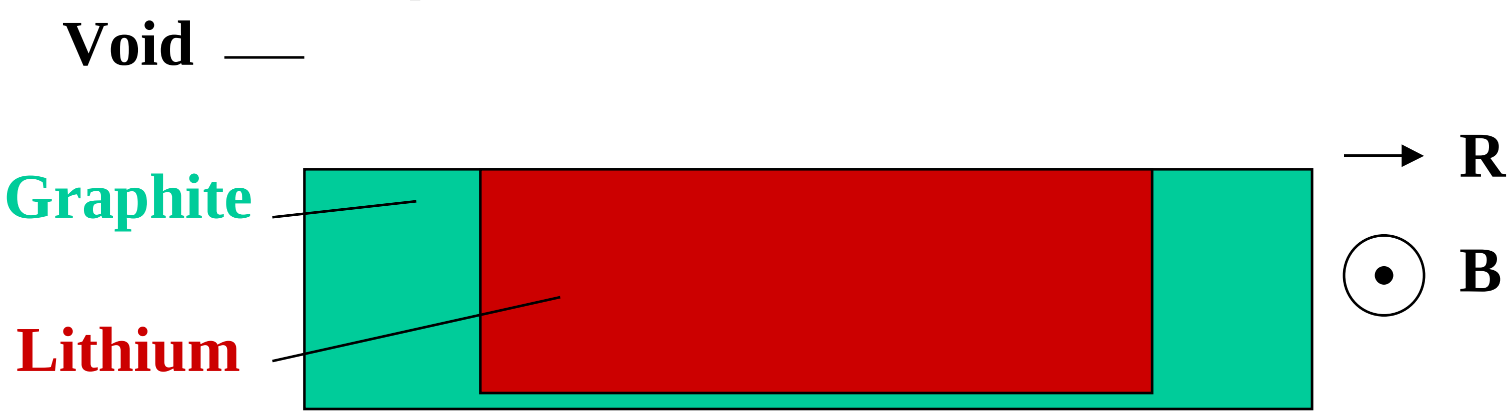
- Preliminary calculations utilized a 2D Navier-Stokers approximation (motion and current in xy-plane, pictured below) using induction formulation and VOF free surface tracking

$$\frac{\partial B_i}{\partial t} + (\vec{u}\cdot\nabla)B_i = -\nabla\times\frac{1}{\sigma\mu}\nabla\times B_i\hat{z} - (u\cdot\nabla)B_a - \frac{\partial B_a}{\partial t}$$

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u}\cdot\nabla)\vec{u} = -\frac{1}{\rho}\nabla\left(p + \frac{B_i^2}{2\mu}\right) + \frac{1}{\rho}\nabla\cdot\tau + \vec{g} + \frac{1}{\rho\mu}(\nabla\times B_i\hat{z})\times B_a\hat{z}$$

$$\frac{\partial F}{\partial t} + (\vec{u}\cdot\nabla)F = 0, \quad \nabla\cdot\vec{u} = 0$$

- Graphite can be treated with electrical (and wetting) properties of the void, or the liquid



Example Case – shows typical Li movement to outboard

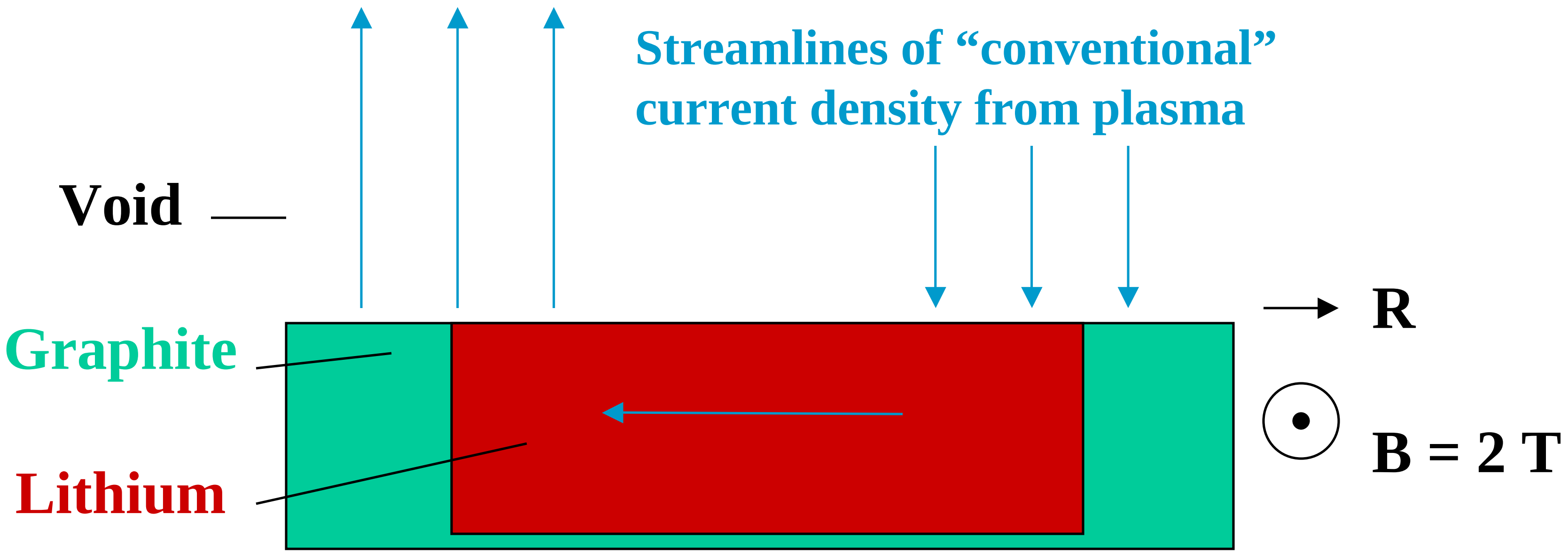
Attempt to simulate the case where current comes from the plasma and exits through the bottom of the liquid film

- Surface tension turned on – side walls not wetted
- Initial depth – 5 mm, instantaneous melting at t = 0
- Applied current density at upper boundary that automatically varies exponentially between 1 to 50 kA/m^2 depending on height of liquid below

Reversing-Direction Top Current Scenario

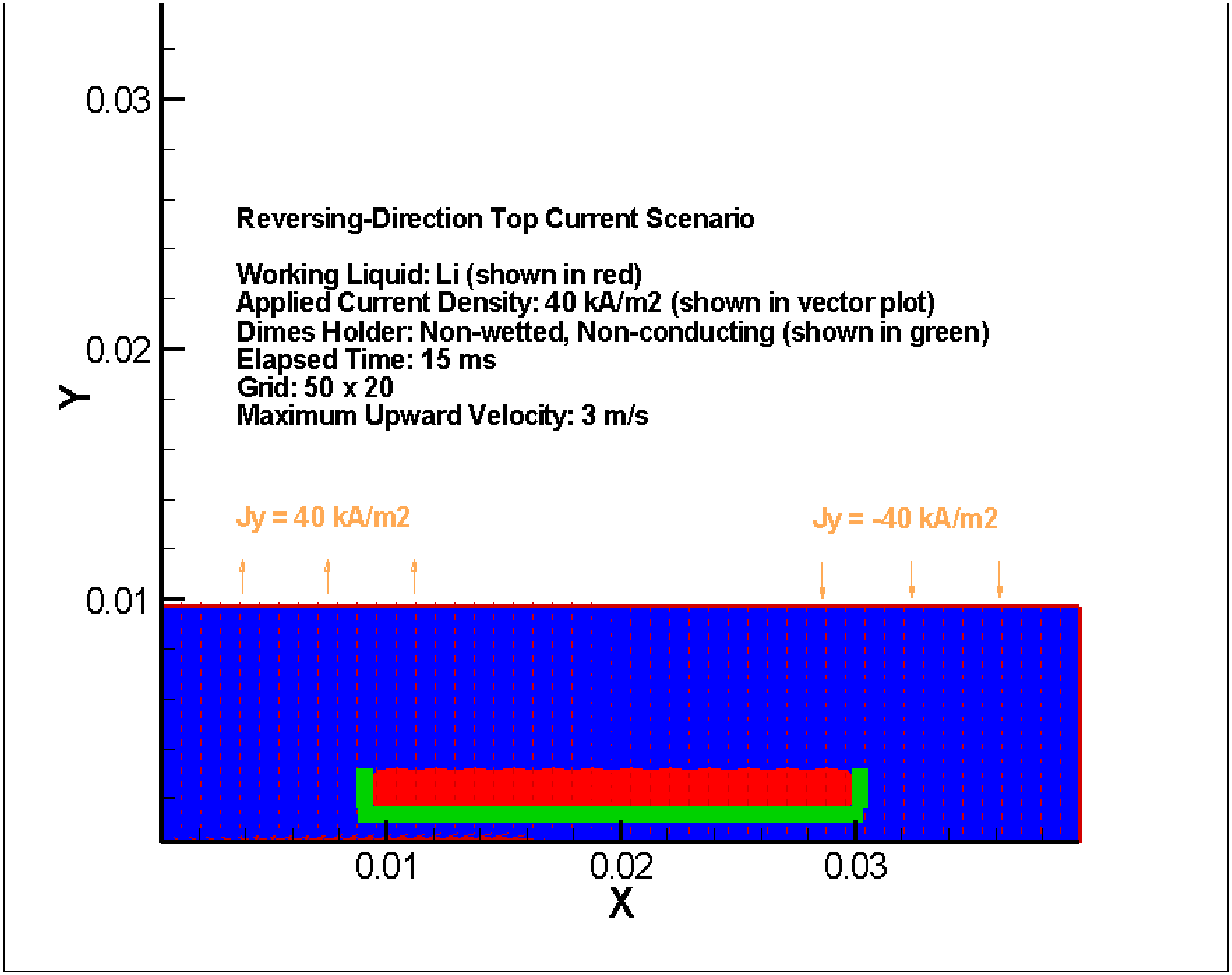
Attempt to simulate location of separatrix directly over DiMES sample

- Assuming 40kA/m^2 current density gives about 20 A coming into the DiMES sample. Amplification of the current density as liquid rises was not included, since **40kA/m^2 should be worst case normal incidence current flux** based on GA guidance



Reversing-Direction Top Current Animation

Graphite assumed to be non-wetted and poor conductor

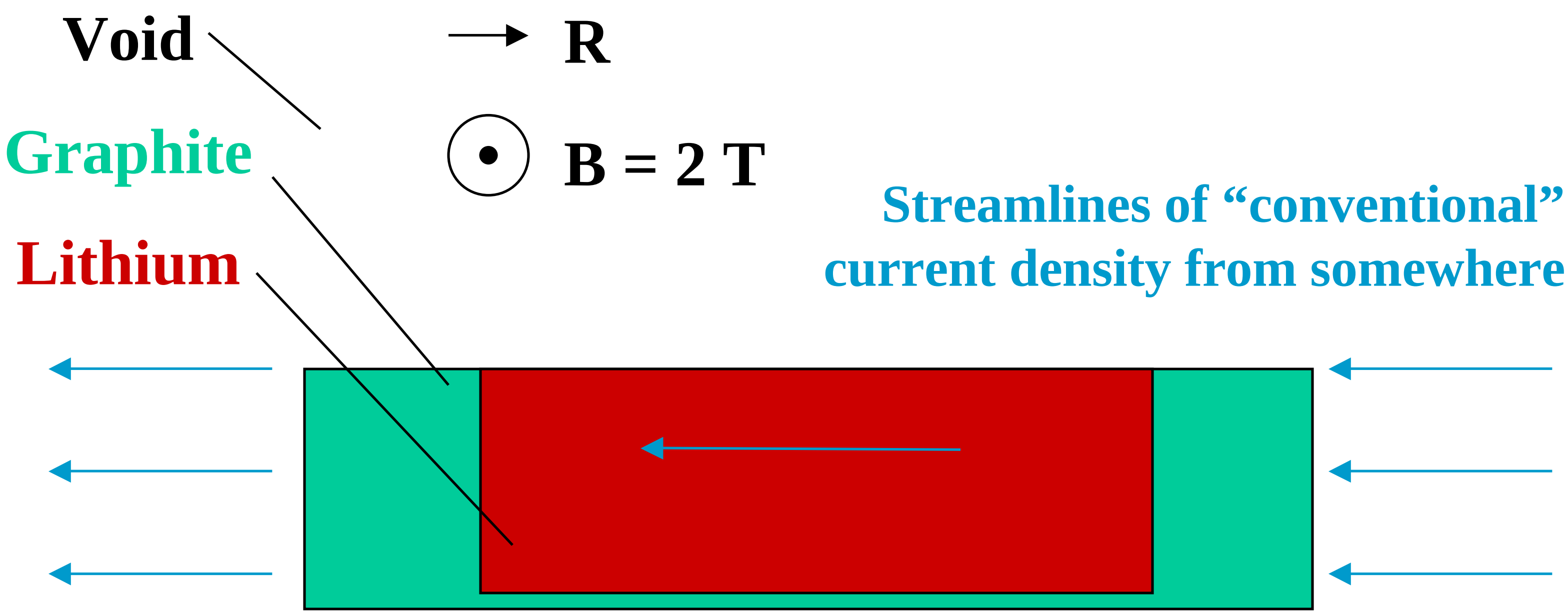


Side Current Scenario

Simulations made to assess how much current might be coming through the tiles.

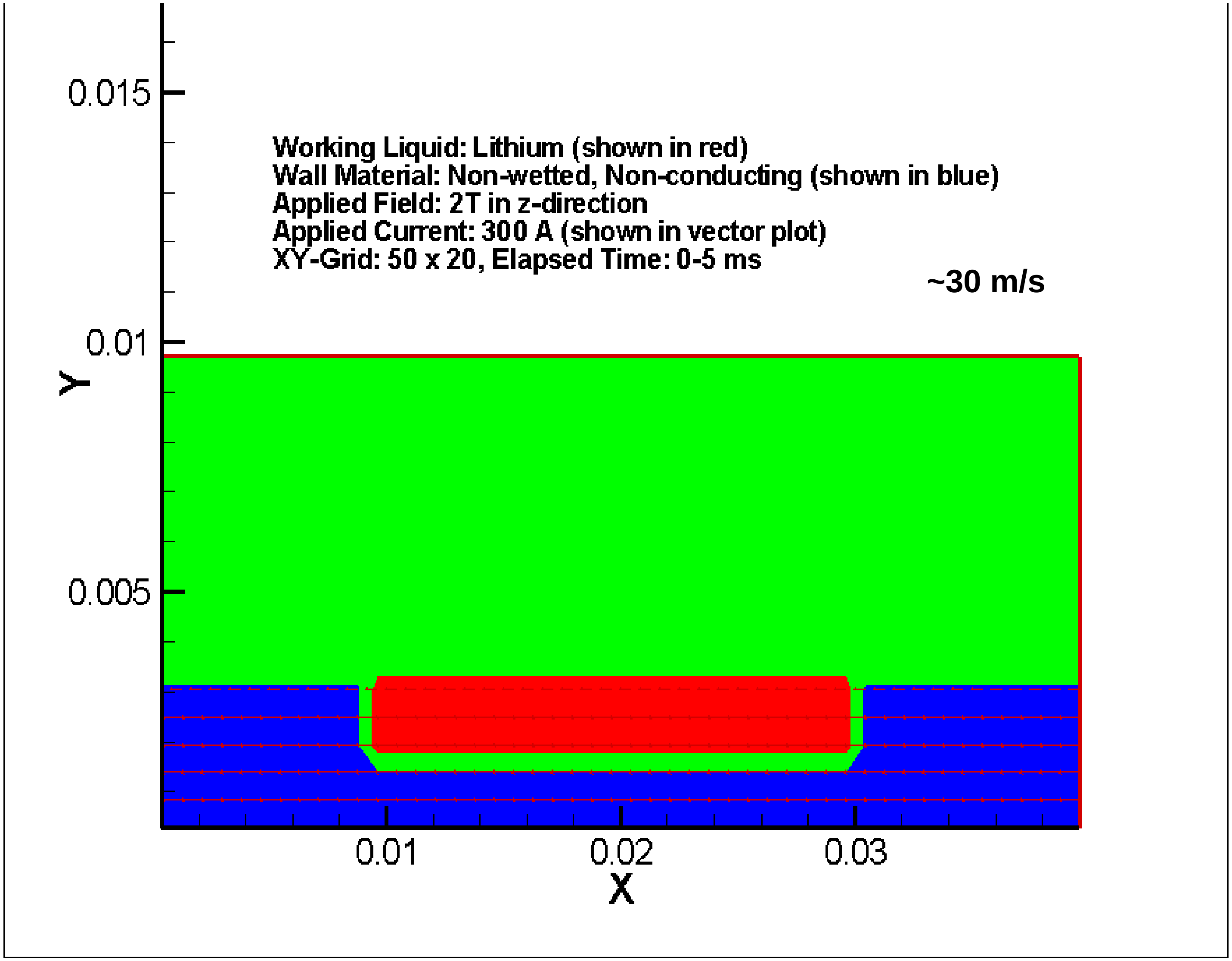
Sort of current collection effect closing horizontally through the tiles.

How much current is necessary to cause significant droplet velocity?



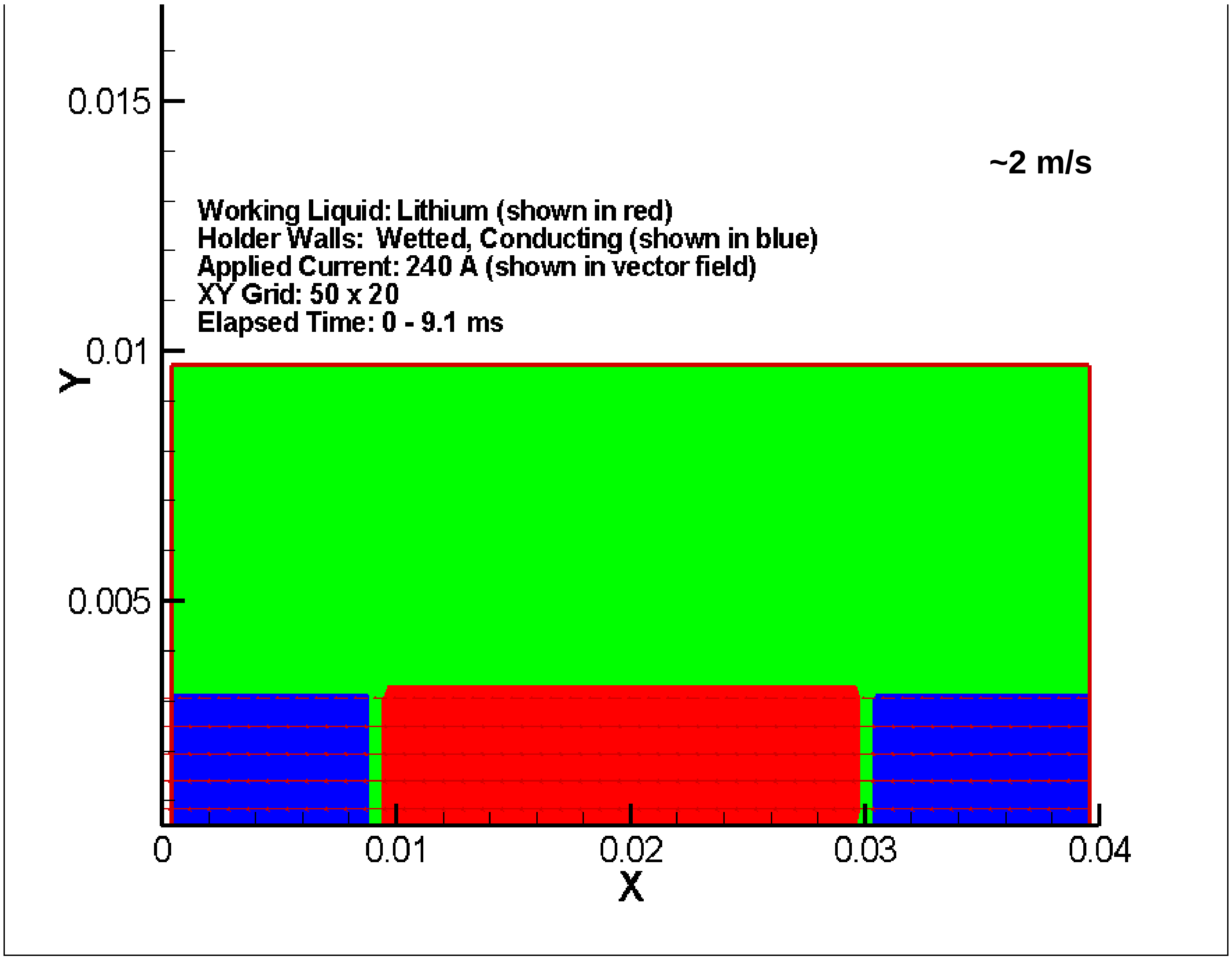
Side Current Scenario Animation

Graphite assumed to be non-wetted and poor conductor



Side Current Scenario Animation

Graphite assumed to be wetted and good conductor



Summary of observations

- **Top current (exiting through tile) case with current amplification shows typical movement of film to the outboard and slow droplet ~1-3 m/s movement upward.**
- **Reversing current from top generates in the worst case a couple m/s upward velocity.**
- **Side current simulations show that about 300-400 A of horizontal current through the DiMES sample is need to generate ~30 m/s upward velocity with non-wet and non-conducting interface.**
- **If the sample is wetted, longer destabilization times and lower upward velocities are observed with ~2 m/s.**

Possible modeling for DiMES....

Perform modeling looking at:

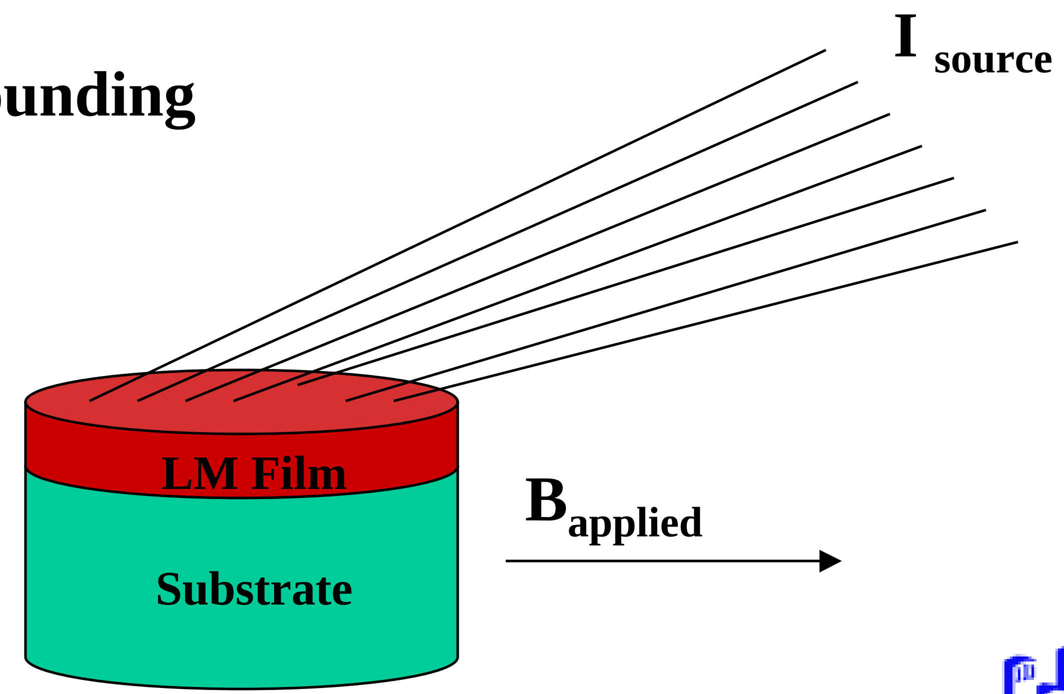
- **3D hydrodynamics**
- **Various assumptions on current closure paths, with current solutions in liquid and solid structures**
- **(Simple) Plasma models with**
  1. **current or potential source**
  2. **Heat source**
  3. **particle (momentum) flux**

Tools exist at:

- **UCLA/HYPERcomp**
- **Brookhaven**
- **Argonne**

Possible Experiment for DiMES Simulation

- **Simulate flux tubes with 3D thin wire array**
- **Independently control length/voltage off wires**
- **Control substrate grounding**
- **Pulse magnetic field or voltage and observe metal motion with fast cameras**



Recommendations for DiMES experiment demonstrating to mitigate of lithium motion

- **Make sure lithium is wetted to metallic liner**
- **Liner sits on (ceramic) heater to pre-melt and control temperature. Use thermocouple measurement on liner or in lithium film**
- **Control electrical contact of metallic liner with DiMES tile – from fully isolated to shorted. Measure current flow between the two.**
- **Diagnose electric potential at select liner locations**
- **Fast visual/thermal imaging of lithium surface (1000 Hz)**

POTENTIAL SCENARIO

Solid lithium got melted, balled up and the interface became detached.

Alternate direction parallel current passed through the sample with focused current density.

And sent the Li upward at high speed, due to JxB effect.

Counter measure:

Make sure that the tile current can be conducted away from the lithium.

DIMES EXPERIMENT PROPOSALS FOR 2003

Melted Li-DiMES with conducting (wetted) interface **GA-Wong**

Li-mist experiment to distribute ELMs power **GA-Evans**
(Simulated by thin foil, W-porous disc, and/or Mo-mesh)

This is the first proposal on the active diffusion of the focused ELM's power. This effect could also be modeled by Rognlien.

Sputtering Li transport in ultra low power **GA-Evans**

The goal is to increase Li-concentration in the SOL, above the threshold of core-Li detection. This is mainly for Li-transport modeling.

SOL current measurement with higher spatial resolution **GA-Evans**